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# THERMAL TESTS FOR ILLUMINATING GLASSWARE

by

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*(Paper read on Tuesday, February 11th, 1936.)*

## General.

This paper does not pretend to suggest a final solution for the problem of testing the thermal properties of illuminating glassware. Rather, it describes some of the difficulties encountered by the authors (and others) when attempting to assess the thermal strength of lighting glassware, and gives an account of the position which has now been reached. It is hoped that the paper will be of assistance not so much because of the information contained in it, but by virtue of the discussion which it may evoke.

The testing of glassware for thermal properties has a fundamental difficulty that practically all such testing involves the destruction of the sample under consideration. A similar state of affairs exists in the examination of, say, electric lamps or gas mantles. But in these cases much information can be obtained without destructive tests: further, the samples are comparatively cheap and plentiful, so that a statistical survey can be made in a manner which is not usually possible for opal or similar diffusing glassware.

The type of test sought after was one which can be applied by a contractor or user so that, given a complete fitting, he can determine whether or not the unit is likely to be satisfactory in normal service. Obviously, therefore, the test must be simple and this rules out, in the early stages at least, tests involving a determination of expansion coefficients or similar properties of the glass.

One of the simplest experiments available for testing the thermal endurance of glassware consists in allowing the fitting to burn until it reaches a steady temperature, and then plunging into cold water: the temperature of the water is chosen so that the bowls which survive are those which would be satisfactory in normal service.

## Type of Test.

This was the type of test proposed in British Standard Specification No. 324, 1927, dealing with Translucent Glassware for Illumination Fittings for Interior Lighting. The first edition of this specification published in January, 1928, contained the following paragraph:—

"The fitting shall be so constructed that when used under normal working conditions no portion of the glassware reaches such a temperature as to cause cracking or the likelihood of deterioration.

The glassware of the fitting shall be capable of withstanding without fracture or injury the following test:—

After operation for one hour under normal working conditions the light source shall be extinguished, and within 30 seconds of this extinction the whole fitting or the glassware alone (whichever shall be mutually agreed by the parties using this specification, having regard to the design of the particular fitting in question) shall be plunged vertically into water at a temperature of 50°F., the glassware being totally immersed. Clamping screws or similar devices shall be slack throughout the test."

## Examination of Original Bathing Test.

Quenching Tests employing this formula soon showed it to be unnecessarily severe, since it rejected fittings known to be satisfactory in service. Experimental work was therefore undertaken to determine more suitable values for cooling period and water-bath temperature.

The object of any forced test, such as this bathing test, is to simulate experimentally the severest possible conditions which the fitting is expected to withstand, and to obtain these conditions with the minimum amount of uncontrollable variation in the factors present, or, alternatively to provide a very severe test which can be correlated with practical results. For opal bowl bathing tests, it seems reasonable that the fitting should be heated by burning with the lamp with which it is usually equipped until a steady maximum temperature is obtained. It is important that the ambient temperature should be controlled (or allowed for) so that the maximum temperature reached by the glassware is definite. A value for the ambient temperature which has been found convenient is 20° C.

Having fixed the temperature of the glassware, there are two main methods by which the test can be varied, namely:—

(1) Alteration of water-bath temperature.

(2) Alteration of time elapsing between turning off the heating source in the fitting and immersion of the bowl.

The second of these methods, although of use in certain special cases, which will be mentioned later, was not considered satisfactory with long time-intervals for general purposes, because of the uncontrollable variations occurring during the comparatively long period between turning off the fitting and bathing the bowl.

These variables are as follows:—

(1) The temperature drop in the bowls during cooling is large (100° C. in two minutes has been measured on one of the hottest gas-fitting globes).

(2) This temperature drop will vary with many factors, e.g., specific heat of glass, thermal capacity and conductivity, ambient air-temperatures draughts, etc., which, over a period of several minutes, will make the fall a very uncertain quantity.

(3) Processes of equalisation of temperature throughout the bowl will occur. These will reduce considerably the chance of cracking, and the effect will probably be different for different bowls.

These three objections to the test are all largely eliminated by employing method (1), since the cooling period can then be made as short as convenient—say, less than one minute—thus reducing effects (1), (2), and (3) to a minimum.

Experiments were carried out, therefore, on representative bowls to ascertain a water temperature at which standard bowls normally used for interior lighting could be bathed in order to distinguish between good and bad samples.

For the first experiments, eight opal bowls, which had been in service for periods varying from a few months to five years and whose thermal properties were, therefore, known to be satisfactory, were subjected to the standard B.S.I. test, but with water-bath temperature considerably above the 10° C. given in that test. Each bowl was heated for a minimum period of one hour with its regulation lamp; by this time, the neck temperature had reached a steady maximum. When the bathing test was to be performed, the fixing screws were slackened off, the bowl being held in position by hand: the light source was then switched off, the bowl being plunged base downwards into water of known temperature. The immersion was begun fifteen seconds after switching off, and was always completed within five seconds. The water-bath temperature ranged from 50° C. downwards. A bowl under test was first heated for one hour and then bathed in water of sufficiently high temperature to ensure that no fracture could occur. The water temperature was then lowered in 5° C. steps and the bowl repeatedly immersed after one hour's burning until the critical cracking temperature was found.

All tests were performed using the type of lamp with which the fitting had been equipped during life, care being taken that the filament location was also the same.

The results of the tests are given in Table I, the figures in Column V. showing the temperature at which the bowls actually cracked, having survived bathing at a temperature 5° higher.

A further series of measurements was made on gas globes with the following results.

Fifteen types of bowl were examined, and were subjected to repeated bathing-tests, as described above. It was found that, in order to avoid excessively high water-bath temperatures, it was necessary to increase the cooling period to 45 seconds. With this value, the water-bath temperature required to pass a satisfactory bowl was found to be 55° C. These tests did not include observations on fittings running at temperatures above 225° C., i.e., they did not include tests on heat-resisting glassware running at very high temperatures.

**TABLE I.—Results of Bathing Tests on Bowls.**

| No. | Bowl Material | Temperatures | | Critical Water Temp. | Result of Test | Critical Water Temp. Corrected for Ambient of 20°C. |
|---|---|---|---|---|---|---|
| | | Ambient. | Total Neck. | | | |
| I | II | III | IV | V | VI | VII |
| 1 | Pot Opal | 22°C. | 84°C. | 20° | Cracked | 18°C. |
| 2 | ,, ,, | 22°C. | 84°C. | 16° | ,, | 14°C. |
| 3 | ,, ,, | 18°C. | 100°C. | 25° | ,, | 27°C. |
| 4 | ,, ,, | 20°C. | 85°C. | 15° | ,, | 15°C. |
| 5 | Cased Opal | 25°C. | 95°C. | 30° | ,, | 25°C. |
| 6 | ,, ,, | 25°C. | 95°C. | (10°) | Survived | (5°C.) |
| 7 | ,, ,, | 30°C. | 100°C. | 40° | Cracked | 30°C. |
| 8 | ,, ,, | 30°C. | 100°C. | 40° | ,, | 30°C. |

Subsequent experiment has shown this test to be satisfactory in passing bowls which have proved safe under service conditions, and in rejecting bowls of doubtful quality: this test has, therefore, been accepted as standard for a large class of bowls, namely, indoor lighting fittings under normal conditions of use, and for this field the test is now incorporated in B.S.S. 324-1934, and reads as follows:—

"The glassware and the canopy shall be so designed in relation to each other that the glassware shall withstand the following test without fracture or other injury:—

After operation for one hour in normal working conditions, the light source shall be extinguished, and the whole fitting or the glassware alone (whichever shall be mutually agreed by the parties using this specification) shall be plunged, after a lapse of time of 45 seconds, into water at a temperature of 55° C., the immersion being completed within a further five seconds.

NOTE.—It is pointed out that it is impossible to formulate a satisfactory acceptance test for the thermal endurance of lighting fittings for use under all conditions. The test described above is designed for interior lighting fittings under reasonable conditions of use."

Although this test is now actually formulated and used, further correlated evidence on its application is very desirable.

## Extension of Tests.

The importance of having standard tests to classify the thermal properties of glassware, is naturally recognised by lighting engineers, and having fixed the bathing test already described, an attempt was made to extend it to other types of fitting and other conditions of service than those required in the initial stages of the application of the test.

It may be stated immediately that no definite extension of the test has yet been agreed, and that considerably more experimental work will need to be done before such a test can be made standard.

The results obtained so far tend to show that glassware for exterior use (or equally arduous conditions)

will have to be divided into two or more classes according to the type of fitting. Experiment and practical experience in testing such glassware indicates that the higher the glass temperature, the more severe the test necessary to distinguish between good and indifferent globes.

In order to test fittings with a glass temperature of the order of 100° C. various types of electric light fitting, normally intended for interior use, have been erected and burnt in the open air for periods of six months or more. In these tests there has been a deliberate attempt to vary the conditions of service by using in the fittings lamps whose ratings were not the correct ones for the bowls in question, so that some fittings ran above the others below their normal temperature. As a result of these experiments, it would appear that the bathing test could be similar to the existing B.S.S. 324-1934 test in form, having a 45-second cooling period and a water-bath temperature between 25° C. and 55° C. The evidence available is too slight to make this figure any more definite. It should be noted that the bowls used in this test were made of flashed and pot-opal.

For bowls of higher operating temperature (200° C. to 300° C.), made of heat-resisting glass, the corresponding values which a few tests have suggested seem to be 30-seconds cooling period after turning-off the heating source and a water-bath temperature of 10° C. These figures are based upon experience gained in testing glassware for the Gas Light and Coke Co. which issues annually over 250,000 items of glassware of various types for lighting purposes. It must be emphasised again, however, that the suggested values for this test are only tentative and require a good deal more systematic investigation.

### Mass Production Testing.

The tests already described are more particularly for the use of the consumer who wishes to examine the fitting as a whole, but more specialised tests can be used by the manufacturer or the testing authority. For example, a manufacturer knowing the conditions under which his glassware is to be used can subject it to a modified bathing-test consisting of plunging the bowl first into hot and then cold water. Experiments carried out on these lines indicate that the temperature drop during this bathing should be the same as the temperature drop for the hottest part of the bowl when subjected to the standard test. Table II. shows the results of tests made on 29 14"-diameter, flashed-opal spheres. Each sphere was bathed first in hot water and then in cold, the time of transference from one bath to the other being between 5 and 10 seconds; the temperature difference between the baths was increased during successive bathings, until the bowl cracked under test.

Each bowl survived bathing with a smaller temperature than the value which caused cracking.

The average temperature difference to cause cracking taken from these figures is 57°C.

Six of these bowls were subjected to the standard type of bathing test, in which the whole fitting is burnt for one hour and then immersed in water after 45 seconds cooling. The average water-bath temperature which cracked the bowls was 26°C. The temperature of the hottest part of the bowl as normally used was 83°C. (average), and the corresponding temperature drop, therefore, is 57°C. Thus the two types of bathing test showed good agreement. Such agreement, of course, has not much significance in face of the variations shown in Table II., but it does indicate that this more rapid type of test can probably be employed.

The spread of results shown by Table II. requires some comment. The bowls tested were all nominally identical, and the spread represents unavoidable variation. This spread of results is not remarkable in the light of other similar bathing-tests. For example, the results have been published of thermal-shock tests made on the simplest of glass articles, viz., glass-rods.* In these tests, which were designed to be as simple as possible, glass-rod was drawn without manipulation from the furnace and annealed. Under carefully controlled conditions the rods were heated to 100°C. and dropped into water at 20°C. Those which did not crack were returned to the furnace and quenched from a temperature of 105°C. The quenching temperature was raised in 5°C. increments until all specimens had cracked.

The critical temperature-change found varied from 130°C. to 160°C. That is to say, that some specimens could be heated to 180°C. and then plunged into water at 20°C., whilst others could only be heated to 150°C. if they were to withstand immersion without cracking.

Every effort had been made to ensure that all specimens of glass tested should have the same physical properties. Hence the spread of 130°C. to 160°C represents the best accuracy of observation which could be obtained in such thermal-shock experiments, even on the simplest type of test which could be made.

Stated statistically, the coefficient of variation of results was about 10 per cent. A similar degree of

* The Application of Statistical Methods to the Quality Control of Manufactured Products. B. P. Dudding and I. M. Baker. "Journal of the Society of Glass Technology," Vol. XVII., No. 67, September, 1933.

**TABLE II.**

| | Temp. diff. at which 14" diameter flashed-opal spheres cracked on bathing test. | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Temp. Diff. °C. ... ... ... | 44 | 51 | 53 | 54 | 55 | 56 | 57 | 58 | 60 | 61 | 62 | 63 | 65 | 66 | 71 | 74 |
| No. of Bowls Cracked ... ... | 1 | 1 | 1 | 4 | 2 | 1 | 5 | 1 | 3 | 3 | 1 | 1 | 1 | 1 | 2 | 1 |

variation has been associated with tests on other simple shapes of glassware.*

Because of the spread in results which is likely to occur in thermal-shock tests, it is evident that the best approach to the problem of testing large numbers of globes would be a statistical one. In its simplest aspect this means knowing (from previous experience or experiment), not only the temperatures at which the bathing tests are to be carried out, but the limits of tolerance allowable in the number of globes which can fail the test without making it necessary to reject the whole batch. This is the method adopted by one firm who manufacture bottles and similar articles. The test used here for bottles is to fill them with hot water while immersed in running cold water. The temperature difference used is of the order of 60°C., and is varied according to the size of the bottle. Batches of twenty-five to thirty bottles are tested at a time, and three or four breakages are expected from an average batch. By taking such tests at regular intervals during the day the quality of the bottle can be checked constantly.

The same firm makes tests on pressed glassware by bathing first in hot water and then immersing in cold water on the outside only, thus giving the glass an outside tension. Here again, batches of twenty articles are tested, and the permissible breakage is three or four.

The testing schedule employed by the Stores Testing Department of the Gas, Light and Coke Company, Watson House, varies according to the type of glassware, but the two tests which cover most bowls are the standard B.S.I. test ( forty-five seconds cooling and 55° C. water bath), and the test for high-temperature heat-resisting glass as mentioned earlier (thirty seconds cooling and 10° C.); experience has shown these tests to be satisfactory.

Certain types of glassware have been tested by lengthening the cooling period to several minutes, and where sufficient is known of the type of fitting under examination, this method of testing has also been found satisfactory.

At the Research Laboratories of the General Electric Company, Ltd., two interesting tests for glassware are used. The first is a " water-drop " test for the thermal properties of glass, and consists of allowing water-drops of known size and temperature to fall on to heated samples of the glass. The general procedure is as follows: for each weight of water-drop, six samples of the glass under test are taken and heated on a hotplate to a known temperature. Water-drops are then allowed to fall, one at a time, on to the specimens, any cracked samples being removed. The temperature of the glass specimens is now raised, and the test repeated. The percentage of unbroken samples at any given temperature is thus determined, and from these data it is possible to form an estimate of the thermal-strength of the glass. This test has the advantage that only small specimens need be employed, and a large number can easily be examined. However, the test is for glass quality only, and not for a complete bowl. It is hoped that a fuller account of this test will be published in the near future.

A method of testing for complete fittings which has been found of value, is an artificial rain test. This test was devised to bear some similarity to conditions encountered in practice, but with a very large factor of safety.

Water-spray from a specially designed nozzle, and equivalent to rainfall of forty inches per hour is directed on to the unit placed in the open air: this is about four times the maximum natural rainfall ever recorded anywhere in the world. The unit is heated by its own lamp until a steady temperature is reached and the water is then sprayed on to the fitting.

In order that a test can be made with the water-drops at a definite angle, a vertical fan of spray is used, as shown in Fig. 1. Drops at the top of the fan are directed upwards, those in the middle horizontally, and those at the bottom downwards. By the selection of one part of the fan, drops incident at any given angle can be directed on to the lantern.

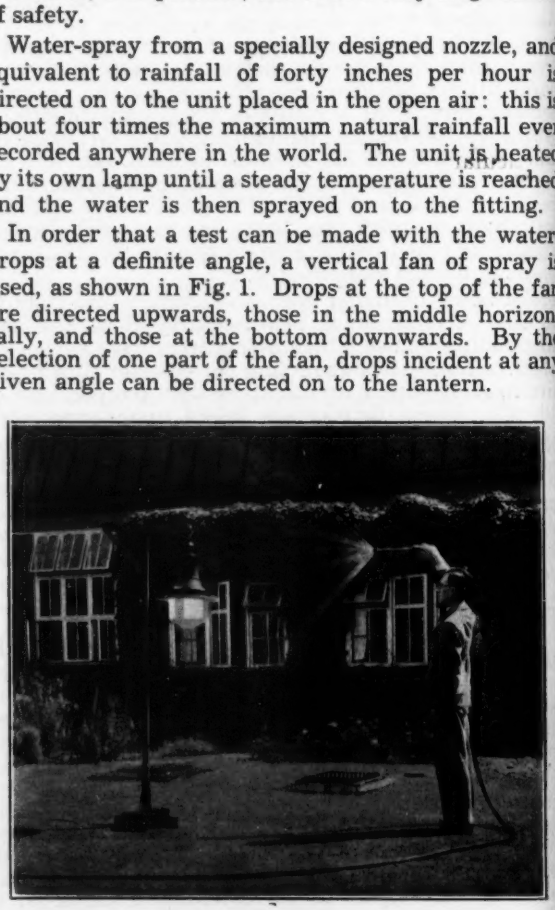

Fig. 1.

### Effect of Repeated Bathing of Bowls.

A few words should be said concerning the effect of repeated bathing of bowls. It is generally believed that repeated bathing of glassware tends to weaken it so that a bowl might pass a bathing test once and fail the next time.

In order to obtain some evidence on this point, two fourteen-inch diameter flashed-opal spheres were equipped with suitable electric lamps, and after burning for one hour were subjected to a bathing test

* The Thermal Endurance of Glass. C. E. Gould and W. M. Hampton. "Journal of the Society of Glass Technology," Vol. XIV., No. 188, 1930.

with the water at 35° C. This temperature was determined as the lowest temperature which did not usually break similar bowls.

The bowls were subjected to repeated bathing under these conditions, and both bowls survived twenty immersions with the water at 35° C. A series of bathing tests was now commenced on these two bowls with a water-bath temperature of 30° C. The bowls cracked on the third and fourth immersion respectively. Two further bowls tested under similar conditions (45 seconds cooling and 30° C. water-bath temperature) cracked on the third and ninth immersions respectively.

The possible reasons for cracking seem to be:

(a) Weakening by bathing.

(b) That the bowl may be immersed in more than one way, and may escape cracking by virtue of the particular method of immersion employed.

The second possibility is certainly unlikely, because one bowl survived eight times before cracking. Since the method of immersion was, as far as possible, the same each time, it is difficult to suppose that the ninth test had some peculiarity which caused cracking. (It should be mentioned here that the manner in which the bowl is immersed (i.e., neck first or last) seems to make little difference to the result of the test, and no data on this point have been obtained.)

One is forced to conclude, therefore, that successive bathing does weaken glassware. A possible explanation is that minute cracks present in the glassware are gradually enlarged by the rapid expansion and contraction of heating and bathing, and eventually the glass fractures. However, since two bowls survived twenty immersions at 35° C., and then cracked at 30° C., it seems probable that, provided that the bowl is not very near its temperature limit (in this case 30° C.), repeated bathing will not have a very serious effect.

## Conclusion.

In conclusion, the authors wish to point out that the amount of work which has so far been recorded on these thermal endurance problems is quite insufficient to form the basis for an unassailably sound specification, and it is very desirable that manufacturers and others interested in glassware should endeavour to obtain data from which definite conclusions can be drawn.

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The authors wish to thank the directors of the Gas Light and Coke Company and the director of the Research Laboratories of the General Electric Co., Ltd., for permission to publish these results.

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# HEAT RESISTING GLASSWARE WITH SPECIAL REFERENCE TO TESTS FOR QUALITY

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SUMMARY OF CONTENTS.

Introduction—Physical Properties—Classes of Glass and Composition—The Effect of Composition on Physical Properties—Defects—Control of Quality—Tests—Commentary on Tests—Extension of Tests.

## INTRODUCTION.

In prefacing, with a general statement, the subject of tests for the probable performance of Heat Resisting Glass, the author would like to make it clear that no attempt is being made to discuss in any way manufacturing processes or the relation of those processes to the physical and chemical properties which together make for good quality glassware. It is to be considered more as an introduction to record his impressions of the chemical and physical aspects of the subject with a view to creating wider interest in modern Heat Resisting Glassware and to defining the conditions with which such glassware, likely to be economical or satisfactory in use, should comply. It is also hoped that this may lead to further co-operation and the pooling of information on the subject by all interested parties.

To-day, heat-resisting glassware finds many applications, both in industry and the home; among these the more important are perhaps glassware for gas and electric lamps, miners' lamps, boiler gauge glasses, thermometers, chemical equipment, and domestic utensils. It is, therefore, reasonable to suggest that a series of tests for quality and suitability in use is necessary to safeguard the manufacturer of repute and to guide the user in selection.

The glassware in which the author is particularly interested is that used in gas and electric lighting units, the conditions of use in which are among the most severe.

It is desirable in prefacing the subject to point out that certain physical properties, such as tenacity, elasticity, expansibility, and what is possibly more important, thermal endurance, which term is recognised as representing a combination of several factors, indicate very definitely the degree and rate of heating, and cooling to which the glass may be subjected without danger of fracture.

Most modern heat-resisting glasses are of the borosilicate type, and since the war the increased availability and the fall in price of boric oxide has made it commercially possible to use it in the manufacture of heat-resisting glass, with the result that many new types of glass have been produced.

## Physical Properties.

It is essential that illumination glassware should be capable of withstanding the mechanical and thermal shocks to which it is subjected during normal life. These shocks are occasioned by rough usage, trucking, washing, sudden heating and cooling, draughts, rain, and numerous other factors.

(i) MECHANICAL STRENGTH.

The mechanical strength of the glass is its ability to withstand mechanical shocks, and is dependent on the elasticity and tensile strength. Hardness gives resistance to scratches and surface disfiguration, and is also of importance.

(ii) DURABILITY.

By durability is meant the power of the glass to maintain its quality without undue deterioration, as shown by filming or clouding, sweating or pitting, discolouring, and other faults mentioned under Defects, and could, perhaps, be better described as wearability. Glass may have to be capable of resisting atmospheric conditions, dust, water, aqueous solutions of salts, alkalis, and acids. Since heat-resisting glass is used for outdoor lamps, chemical ware and food containers, etc., its powers of resistance must be high, as it has to withstand the action of foods, chemicals, and, in the case of lamps, extreme atmospheric conditions, which are liable to affect the light efficiency.

(iii) THERMAL ENDURANCE.

The thermal endurance of the glass, that is, its ability to withstand thermal shocks, is dependent on the following characteristics:—

(a) tensile strength.
(b) elasticity.
(c) coefficient of linear expansion.
(d) specific heat.
(e) coefficient of heat conductivity, and
(f) density.

The term was first introduced by Winkelmann and Schott to denote the power of glass to resist thermal

shock, and the following formula was given, showing the relation between the thermal endurance F and other characteristics.

Let P = tensile strength.
„ E = Young's Modulus of Elasticity.
„ A = Linear coefficient of thermal expansion.
„ S = density of glass.
„ C = specific heat.
„ K = the conductivity of heat.

Then F can be obtained as an arbitrary figure and is expressed as Thermal Endurance $= \frac{P}{EA}\sqrt{\frac{K}{SC}}$

The above formula, however, has never been satisfactorily confirmed, but as the result of recent research by Hampton and Gould, a simple and practical method of determining the thermal endurance of a glass has been produced by the Standards Committee of the Society of Glass Technology and is described on page 8.

The importance of the above factors in the behaviour of the glass when heated or cooled can best be seen by considering the effect upon the glass when a gas or electric lamp is lighted or extinguished. Upon lighting, the globe is suddenly subjected to a high temperature on its inner surface. The inner layer then presumably expands or endeavours to, while the middle and outer layers are still comparatively cold. Forces are thus set up within the glass and the inner face is in a state of compression and the outer face in a state of tension. If the stress produced is sufficiently large the outer layers will fracture. This initial stage of breakage can often be observed by fine hair-like cracks on the outside and hottest part of the globe. It can be assumed from this that the thermal conductivity and the thickness of the glass have an important effect since slow conduction of heat across the walls results in differential expansion between the inner and outer faces, and produces a state of stress. In this state the possibility of fracture appears to depend largely on:—

(a) the heat conductivity, and
(b) the tensile strength, which must be greater than the stress in the glass if failure is to be prevented.

Sudden changes in profile appear also to have an important bearing for similar reasons.

During the manufacture of glass, as in the casting of metals, internal stresses are set up; these are due to rapid cooling, resulting in weakness, brittleness and liability to fracture, and which can only be removed by heat treatment. This process of relieving or eliminating internal stresses is usually known as annealing. Although both glass and metals are annealed the reason for the greater liability of glass to fracture is due to its comparatively low mechanical strength and heat conductivity, although these are in some measure counterbalanced by a lower expansibility, a higher specific heat, and consequently a lower rate of heating up.

### Classes of Glass and Composition.

To clarify the matter it may be desirable to show the various categories of commercial glass. Ignoring bottle glass, the more important are as follows:—

(a) Pressed glass, used for thick walled vessels, jars, reflectors, glass tiles, electrical insulators, etc.
(b) English crystal glass used for best quality table ware.
(c) Rolled or plate glass used for windscreens, skylights, reinforced wire glass, mirror glass, etc.
(d) Crown and sheet glass used principally for windows.
(e) Optical glass used for microscopes, telescopes, and scientific instruments; and
(f) Heat-resisting glasses.

The chemical compositions of typical examples of these and other glasses are shown in Table I.

By comparing these with Table II. several essential differences will be seen, chief among these being the absence of boric oxide from any but the heat-resisting glasses and the higher silica content in the heat-resisting glasses. In most glasses silica is the main constituent, and a brief reference to the sources of this material may be of some interest.

In modern times sand is used, being cheaper than the crushed flint stones originally used. White sand,

**TABLE I.—PERCENTAGE COMPOSITIONS OF TYPICAL GLASSES.**

| | Common Pressed Glass. | English Crystal (Tableware) | Plate Glass. | Window Glasses. | | | Optical Glasses. | | Electric Light Bulbs. | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Libby Owens. | Fourcault. | Handmade. | Hard Crown | Med. Flint. | Lead Glass. | Lime Magnesia. |
| Silica ($SiO_2$) | 72.0 –74.0 | 53.0 –55.5 | 72.0 –73.0 | 72.0 –73.0 | 70.0 –73.0 | 71.0 –72.0 | 71.0 | 46.0 | 58.0 –59.0 | 71.5 –73.5 |
| Iron Oxide (FeO) | 0.04– 0.07 | 0.02– 0.03 | 0.08– 0.1 | 0.15– 0.2 | 0.15– 0.2 | 0.15– 0.3 | 0.3 | 0.02 | 0.04– 0.06 | 0.06– 0.1 |
| Alumina ($Al_2O_3$) | 0.5 – 1.0 | 0.2 – 0.4 | 0.6 – 1.0 | 1.0 – 1.5 | 1.0 – 1.5 | 1.0 – 1.5 | 0.33 | 0.15 | 0.2 – 0.4 | 1.0 – 2.0 |
| Lead Oxide (PbO) | – | 31.0 –35.0 | – | – | – | – | – | 44.5 | 28.0 –30.0 | – |
| Potash ($K_2O$) | – | 11.0 –13.0 | – | – | – | – | 13.0 | 8.5 | 4.0 – 5.0 | 0 – 1.5 |
| Soda ($Na_2O$) | 17.0 –18.0 | – | 12.0 –13.0 | 12.5 –13.0 | 15.0 –18.0 | 11.0 –12.5 | 4.5 | 0.5 | 7.0 – 8.0 | 14.0 –17.0 |
| Lime (CaO) | 7.0 – 8.5 | – | 12.5 –15.5 | 11.0 | 9.5 –11.0 | 14.0 –15.0 | 10.0 | – | – | 5.0 6.0 |
| Magnesia (MgO) | – | – | – | 2.5 – 3.0 | – | – | – | – | – | 3.5 – 4.5 |
| Arsenious Oxide ($As_2O_3$) | – | – | – | – | – | – | 0.8 | 0.3 | – | – |

**TABLE II.—HEAT RESISTING GLASSES.**

| Constituent. | | British. 1 | British. 2 | British. 3 | Pyrex American. | Jena Incandescent Gas Chimney | Jena Miners' Hand-Lamp. | Austrian "Sun Brand" Chimney. | Kavalier Combustion Tube. |
|---|---|---|---|---|---|---|---|---|---|
| Silica | ($SiO_2$) | 80.1 | 75.3 | 72.5 | 80.6 | 73.88 | 73.1 | 76.78 | 79.57 |
| Boric Oxide | ($B_2O_3$) | 12.2 | 11.3 | 13.4 | 11.9 | 16.48 | 17.22 | — | — |
| Soda | ($Na_2O$) | 4.2 | 6.3 | 6.7 | 3.8 | 6.67 | 7.76 | 11.14 | 0.66 |
| Alumina | ($Al_2O_3$) | 2.7 | 3.0 | 3.5 | 2.0 | 2.24 | 1.98 | 0.72 | 0.04 |
| Potash | ($K_2O$) | — | 1.2 | — | 0.6 | trace | — | 4.74 | 11.8 |
| Lime | (CaO) | 0.3 | 0.5 | 0.1 | 0.2 | trace | trace | 6.52 | 7.8 |
| Ferric Oxide | ($Fe_2O_3$) | 0.03 | 0.1 | 0.05 | 0.1 | — | 0.15 | — | — |
| Arsenious Oxide | ($As_2O_3$) | — | — | — | — | 0.73 | — | — | — |
| Magnesia | (MgO) | — | — | — | 0.2 | trace | trace | 0.24 | 0.11 |
| Manganese Oxide | (MnO) | — | — | — | — | trace | — | — | — |
| Zinc Oxide | (ZnO) | — | 2.8 | — | — | — | — | — | — |
| Barium Oxide | (BaO) | — | — | 2.3 | — | — | — | — | — |
| Antimony | ($Sb_2O_3$) | — | — | 1.5 | — | — | — | — | — |

for example, is obtained from Aylesbury, Isle of Wight, Lynn, Belgium, Fontainebleau, near Paris, and Holland. This white sand, on account of its purity, is used for the better class work such as optical glass, chemical ware, crystal glass, etc. Common varieties of sand from Bagshot and Reigate, and even red sand are used for low quality glass such as that for beer bottles, jam jars, etc., where chemical impurities in the silica are comparatively unimportant.

### The Effect of Composition on Physical Properties.

The properties of glass can be controlled to a considerable extent by varying the chemical composition.

(i) *Expansibility.*

It is possible to obtain comparatively small expansibility by suitable adjustment. Generally speaking, glasses rich in alkali have high expansibilty, whilst silica ($SiO_2$), boric oxide ($B_2O_3$), magnesia (MgO), and zinc oxide (ZnO) tend to reduce the expansibility.

(ii) *Heat Conductivity.*

The conductivity tends to increase by increasing the amounts of the oxides $Al_2O_3$, $SiO_2$, $B_2O_3$, MgO or CaO.

(iii) *Tensile Strength.*

Winkelmann and Schott state that glasses containing CaO and ZnO have a high tensile strength, whilst those with $Na_2O$ and $K_2O$ have least.

(iv) *Durability.*

The durability required is dependent on the severity of the conditions likely to be met with in use, particularly with beakers and other chemical containers. It can be stated, however, that oxides which bestow resistance to:—

(a) Water are $SiO_2$, $Al_2O_3$ ZnO, PbO.
(b) Acids, $SiO_2$, $Al_2O_3$, CaO, $B_2O_3$, ZnO, and to
(c) Alkalis, $Al_2O_3$.

(v) THERMAL ENDURANCE.

Table II. shows the percentage chemical compositions of several well-known heat-resisting glasses.

As previously stated the most noticeable feature in the compositions is the high percentage of $SiO_2$ and $B_2O_3$ and the two tables included in Table III. give some indication as to the reason for this. Table A, due to English and Turner, shows the expansion coefficients for the various constituents. Table B deduced by Russ shows the heat conductivity factors.

**TABLE III.—EXPANSION AND THERMAL CONDUCTIVITY.**

**TABLE A.**

| Constituent. | Coeff. of Expansion. |
|---|---|
| Boric Oxide ($B_2O_3$) | $-1.98 \times 10^{-7}$ |
| Silica ($SiO_2$) | $0.15 \times$ ,, |
| Alumina ($Al_2O_3$) | $0.42 \times$ ,, |
| Zirconia ($ZrO_2$) | $0.69 \times$ ,, |
| Magnesia (MgO) | $1.35 \times$ ,, |
| Zinc Oxide (ZnO) | $2.10 \times$ ,, |
| Lead Oxide (PbO) | $3.18 \times$ ,, |
| Lime (CaO) | $4.89 \times$ ,, |
| Potash ($K_2O$) | $11.7 \times$ ,, |
| Soda ($Na_2O$) | $12.96 \times$ ,, |

Coefficient of Cubical Expansion is the ratio of the increase in volume for 1°C. rise in temperature to the volume at 0°C.

**TABLE B.**

| Oxides. | Thermal Conductivity. |
|---|---|
| Silica ($SiO_2$) | .003330 |
| Boric Oxide ($B_2O_3$) | .002704 |
| Magnesia (MgO) | .002295 |
| Alumina ($Al_2O_3$) | .001600 |
| Ferric Oxide ($Fe_2O_3$) | .001528 |
| Zinc Oxide (ZnO) | .001155 |
| Lime (CaO) | .001135 |
| Soda ($Na_2O$) | .000935 |
| Lead Oxide (PbO) | .000850 |
| Potash ($K_2O$) | .000746 |

Thermal Conductivity is the quantity of heat that flows in one second through 1 sq. cm. of a plate 1 cm. in thickness when there is 1°C. difference of temperature between its faces.

### Defects.

From observation of the behaviour in use of lighting glassware, defects appear to fall under the following general headings:—

(1) Breakages due to:—
  (a) Poor Design.
  (b) Unsuitable Composition.
  (c) Accidental Manufacturing Faults.
  (d) Initial Strain Unrelieved.

(2) Durability (Wearability) due to:—

(a) Filming or Clouding.
(b) Sweating or Pitting.
(c) Discoloration.

It is obvious that in any one failure all can be contributing in a lesser or greater degree, and some reference to each may be useful.

(a) Poor Design.

Unsatisfactory results from globes designed with sudden and unnecessary changes in profile and big differences in the thickness of section were familiar years ago, and lighting bowls and globes are still to be found which can be, and have proved to be, very dangerous in use, although fortunately they are much less frequently encountered than in the past.

(b) Unsuitable Composition.

(c) Accidental Manufacturing Faults.

The user is entirely in the hands of the specialist and the manufacturer in this connection, and good results would appear to depend largely upon the knowledge and skill of the manufacturing staff and amount of supervision employed. In fairness to the English manufacturers it can be said that in the past little encouragement was given to them owing to the general acceptance of cheap foreign glassware and the fact that insufficient data were given to them as to the real conditions and requirements of use. Statistics of behaviour in use are costly, sometimes difficult to collect and analyse, and the user was apparently unaware of the large saving which could be effected in maintenance by paying a higher price for a globe specially designed for the conditions it had to meet.

The following statistics in relation to a large Sign of the Research Laboratories of The Gas Light and Coke Company may be of interest. The position is a very exposed one, being on the south side of the Thames and facing the Chelsea Embankment. (See Fig. 1.)

Length 120 ft. Depth—sides 8′ 6″ Middle 13′ 0″
Height above water 70′.

19—7 mantle superheated lamps (8750 B.Th.Us/hr)
8—9 mantle superheated lamps (11250 B.Th.Us/hr)

Distance of lamps from facia 4′ 6″.

The chart (Fig. 2) shows the breakages of mantles and globes on this sign over a period of six years.

The sign was brought into lighting during the first half of 1928. Owing to the very severe atmospheric conditions, breakages of glassware and consequently breakage of mantles was very high and resulted in high maintenance costs and poor appearance of the sign. All possible means were tried to reduce this, constructional details of the lamps being modified and a variety of types of globes experimented with. No very definite improvement was noticeable until after 1930, during which a leading manufacturer of

Fig. 1. A Photograph showing the exposed position of the sign on the river bank.

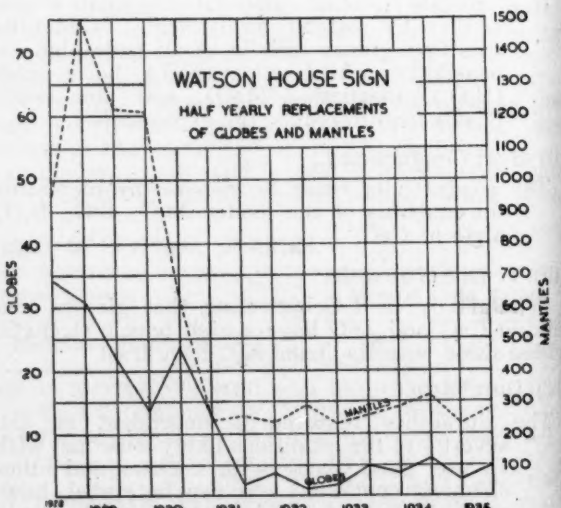



Fig. 2. Records of Replacements of Globes and Mantles for sign outside Watson House, visible from across the Thames.

heat resisting glassware experimented with and finally produced a globe of outstanding thermal endurance with the very satisfactory results shown. It may here be stated that since the adoption of this high quality heat resisting glass no case of breakage has occurred while the lamps have been in use, all breakages being due to handling during maintenance and cleaning.

(d) INITIAL STRAIN.

This is the result of poor annealing, and it is safe to assume that all manufacturers of repute thoroughly understand this problem. It is sufficient to say that the presence of strain in glass can be detected by means of polarised light, and that the majority of manufacturers employ some type of optical instrument such as the strain viewer, or polariscope, working on this principle. Individual failures out of bulk supplies are therefore presumably due to unavoidable manufacturing errors.

(e) POOR WEARABILITY.

Information still appears to be lacking as to what can be considered to be a reasonable length of life for lighting glassware under normal conditions of use. It seems evident that with time deterioration does take place and good quality glass will fracture after months of use for no apparent reason.

Filming and discoloration are often apparent after a short period in use, and it has been suggested that in addition to unsuitable composition of the glass the trouble may be partly due to the composition or finishing treatment of the metal holding or containing the globe.

STATISTICS OF REPLACEMENTS.

It is very difficult for obvious reasons, to obtain reliable figures and distinguish between replacements of glassware due to poor thermal endurance, breakage due to handling, and failure due to poor durability.

Figures available in respect of the highest quality heat resisting glass tend to show that practically all breakages are due to handling during maintenance and that with experienced labour, working under such difficult conditions as public lighting, a reliable replacement figure is in the order of half a globe per lamp per annum. Difficulties of handling large globes of very thin section in awkward positions and under trying conditions will be realised, and this figure is a very reasonable one for public lighting.

High temperatures make difficult the increasing of mechanical strength, by the reduction of globe size and increased thickness of glass, and it is presumed that this is realised by both glass and lamp manufacturers. It is felt, however, that further co-operation and investigation on this matter could be made with advantage.

Breakage in transport is also an important item, but methods of packing have so improved in recent years as to suggest that more care in the handling of the receptacles containing these fragile globes could be taken.

## Control of Quality.

As the result primarily of competitive buying and selling tending to reduce prices and quality, safeguards to both manufacturer and user become necessary. These safeguards usually take the form of specifications and agreed standard tests.

Up to very recently the number of national standard specifications for the various uses of glassware has been very limited, and it is significant that the first specifications produced were for those uses demanding the highest quality.

With the gradual increase in efficiency of gas and electric lighting units, low pressure, super heated, and high pressure gas burners, carbon filament, metal filament and discharge tube electric lamps has come also a steadily increasing temperature in the vicinity of the light source, demanding with each increase in efficiency, glassware with a higher degree of thermal endurance. Until comparatively recent years no engineer would take the risk of fixing an outdoor lamp under which the public had to pass, without safeguarding himself against possible accidents due to fracturing of the globe. The form of protection used was usually a thin wire net around the outer surface of the globe. With all the complexities of glass manufacture and the difficulties involved, manufacturers can be congratulated on their efforts in recent years towards producing heat resisting glassware of such a high standard. The author looks forward to still closer co-operation between the manufacturers and the users with a view to making it easier for the merchant and user to distinguish between satisfactory, indifferent, and poor heat-resisting glass.

## Tests.

The only tests in which the user is likely to be interested so far as heat-resisting glassware is concerned would be for:—

(i.) Wearability, and

(ii.) Thermal Endurance,

and the author is unaware of any national specification which provides for both of these.

(i.) WEARABILITY.

Various widely-used tests exist, and give some indication of the probable behaviour of the glass after prolonged exposure. All these tests are based on the resistance offered by the glass to various reagents and under various conditions, and the most widely used are:—

(1) *Powder Test.*—In this test the glass is ground to powder and is then subjected to hot water under known conditions, the amount of solid dissolved being taken as a measure of the durability. This test is based on the fact that most glass is attacked by $H_2O$, and some alkali is dissolved out.

(2) *Iodeosin Test.*—The glass is immersed in a saturated solution of water in ether, to which a very small quantity of iodeosin has been added. The water attacks the glass, and a small quantity of alkali is set free, which combines with the iodeosin to form a red

alkali salt. This is insoluble in ether, and is deposited upon the surface of the glass, the red coloration indicating the amount of alkali set free, and the wearability of the glass being judged by the intensity of colour.

(3) *Autoclave Test.*—The glass is subjected to the action of water at temperatures of 150° C. or more, the necessary temperature being obtained by heating the glass in an autoclave. In this test not only is the water considerably above normal boiling point, but the pressure is correspondingly high.

(4) In addition to the above numerous other tests exist, such as estimating by the resistance to solutions of acids, alkalis, and salts, such as ammonia solution, dilute sulphuric acid, sodium carbonate solution, etc.

It is hoped that more information will be obtainable as to the possible more general adoption of some simple test which can be easily applied.

(ii.) THERMAL ENDURANCE.

In 1926 a committee was formed by the British Standards Institution, with Dr. J. W. T. Walsh, M.A., D.Sc., M.I.E.E. (head of the Photometric Department of the National Physical Laboratory), as its chairman, to prepare a dimensional and performance specification for "Translucent Glassware for Illumination Fittings for Interior Lighting."

The dimensions covered primarily the gallery and the lip and neck of the glassware, and dealt with a range of electric units with neck diameters from $2\frac{1}{2}$" to 10" only, and a very limited range of gas fittings, only the familiar large, medium, and small burner with neck diameters of $\frac{7}{8}$", $2\frac{3}{4}$", and $3\frac{7}{16}$" being considered.

In the preparation of this specification the glassware was considered primarily from the point of view of its dimensions, diffusing power and brightness. During the discussions, however, it was felt that some test was necessary to provide against fracture due to unsatisfactory annealing, and after some experimental tests the following clause was adopted and published in Specification No. 324-1927.

"The fitting shall be so constructed that when used under normal working conditions no portion of the glassware reaches such a temperature as to cause cracking or the likelihood of deterioration.

The glassware of the fitting shall be capable of withstanding without fracture or other injury the following tests:—

After operation for one hour under normal working conditions the light source shall be extinguished, and within 30 seconds of this extinction the whole fitting or the glassware alone (whichever shall be mutually agreed upon by the parties using this specification, having regard to the design of the particular fitting in question), shall be plunged vertically into water at a temperature of 10°C., the glassware being totally immersed. Clamping screws or similar devices shall be slack throughout the test."

Apparently only comparatively low temperature lighting units were considered, as it was subsequently found, when bringing the test into general use, that it rejected all glassware, except,

(i) that used with a very low temperature light source;

(ii) glassware of well ventilated units or glassware only partially covering the light source;

(iii) glassware used at considerable distance from the light source; and

(iv) high quality glass of very limited foreign origin.

The difficulty of reducing the temperature of the glassware by increasing the ventilation and altering the design and construction of the lamp to suit the glassware then available, was not apparently fully represented. Nor was allowance made for the fact that increasing efficiencies tended towards higher temperatures.

With the improvement in British glass this test was adopted by the Gas Light and Coke Company as their standard test for the highest quality heat-resisting glass as is used to-day on high-pressure lamps and outdoor low-pressure lamps operating in exposed positions. For their own use the Gas Light and Coke Company formulated a second and less severe test, in which the lapse of time between extinction and immersion was increased, and this test was employed on glassware for low-pressure outdoor and indoor lamps used under less severe conditions. By increasing the time, however, it was found that the temperature between the top and bottom of the globe tended to equalise throughout, and on account of this and other uncontrollable factors the test could not be regarded as entirely satisfactory and had to be used with some discretion. Subsequently, it became necessary to revise B.S.S. No. 324 of 1927, and this modified test was abandoned and the new test clause in B.S.S. No. 324 of 1934 used in its place. This is referred to later.

During the review considerable thought was given to the heat resistance clause, and efforts were made to broaden the scope of the test clause so as to make it applicable to lighting glassware generally; the reason for this being that no lighting unit can be truly classified as an indoor or outdoor unit owing to the variety of situations and conditions of use, some indoor situations having possibly more severe conditions to contend with than some outdoor conditions. After extended discussion and experimental work on the part of the manufacturers and the research laboratories of the General Electric Company and the Gas Light and Coke Company, the test clause was again, as a temporary measure, modified so as to apply to glassware for indoor lighting units under normal conditions of use. The modified test

clause, as it appears in B.S.S. No. 324, 1934, reads as follows*:—

"The glassware and the canopy shall be so designed in relation to each other that the glassware shall withstand the following test without fracture or other injury:—

After operation for one hour in normal working conditions, the light source shall be extinguished and the whole fitting or the glassware alone (whichever shall be mutually agreed by the parties using this specification) shall be plunged, after a lapse of time of 45 seconds into water at a temperature of 55°C. the immersion being completed within a further 5 seconds.

Clamping screws or similar devices shall be slack throughout the test.

*Note.*—It is pointed out that it is impossible to formulate a satisfactory acceptance test for the thermal endurance of lighting fittings for use under all conditions. The test described above is designed for interior lighting fittings under reasonable conditions of use."

For convenience of reference the difference between these two tests is shown in Table IV.

**TABLE IV.—SPECIFICATION TESTS (1927 and 1934).**

| Specification. | Period of operation. | Lapse of time between extinction and immersion. | Temperature of water. |
|---|---|---|---|
| 324-1927 | 1 hour | 30 sec. | 10° C. (50° F.) |
| 324-1934 | 1 hour | 45 sec. | 55° C. (131° F.) |

In 1930 the Standards Committee of the Society of Glass Technology produced a provisional standard thermal endurance test, which, although of little use for testing finished lighting globes, may be of interest and use to manufacturers. Briefly the test is as follows:—

A tall conical beaker (nominal 200cc.) of specified shape and size is adopted as the standard test specimen. Ten such specimens are taken and filled with liquid paraffin wax to a depth of 4—5 cms. As a preliminary guide to the approximate cracking temperature one specimen is taken, and the wax heated to, say, 70°C., and the beaker plunged into water at 15°C. This is repeated with increasing wax temperatures until a temperature is reached at which the specimen cracks upon immersion in the water. The remaining test specimens are then heated until the wax is 50°C. below this previously obtained critical temperature, and then immersed in water at 15°C. This is repeated until cracking occurs, the wax temperature being increased by 5°C after each immersion. The temperature of the wax required to cause fracture, and the maximum thickness of the beaker along the fracture are noted. By substitution in the formula shown below, the thermal endurance of the glass is determined.

Thermal Endurance =

$$\text{x } \sqrt{\frac{\text{Temperature Difference}}{\text{Thickness (mms.).}}}$$

This figure is worked out for each beaker, and the average taken as the value for the glass.

Note: By temperature difference is meant the difference in temperature between the water and the wax.

The thickness referred to is the maximum thickness of the glass along the fracture.

### Commentary on Tests.

This method of thermal shocking is fairly common as a test for thermal endurance and it is believed that non-standard quenching tests of this type are frequently used throughout the industry. It is noted that a similar test for chemical glassware is in its final draft and circulated for comments by the B.S.I. This clause reads as follows:—

"The finished viscometer, when empty, shall withstand rapid heating and cooling to 80°C. without cracking. The test shall be conducted by heating the viscometer to 100°C. in a bath of water for five minutes and then transferring it rapidly to water at 20°C. After remaining in the cold water

* See "Thermal Tests for Illuminating Glassware." By S. F. Dunkley and W. R. Stevens, p. 105.

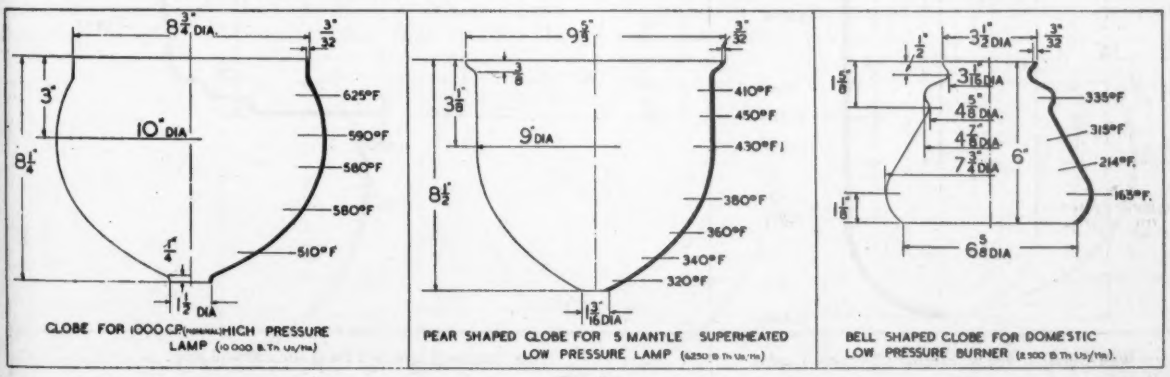



Fig. 5.

CHART SHOWING DIMENSIONS OF GLASSWARE FOR GAS AND ELECTRIC FITTINGS.

*(See also next page.)*

for five minutes the viscometer shall be rapidly replaced in a bath of boiling water."

Some idea of the severity of such a test can best be judged by considering the:—

(i.) Temperatures attained by the glass,
(ii.) Rate of heating up; and
(iii.) Rate of cooling.

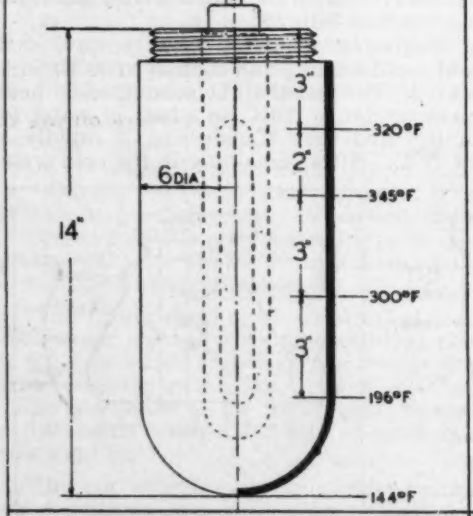
The following show:—

(a) The wide range of temperatures attained by typical examples of glassware used on gas lighting units. (Table V.)

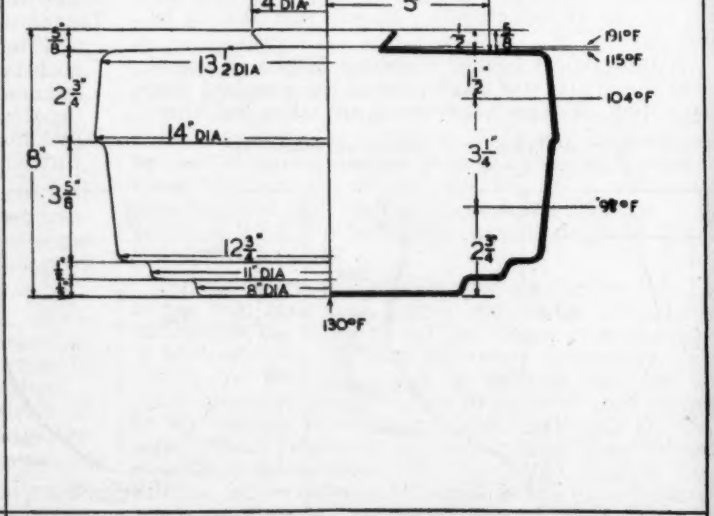
(b) The graduation in temperature on typical examples of gas and electric globes. (Figs. 5 and 6.)

**TABLE V.—DIMENSIONS OF GLASSWARE AND TEMPERATURE ATTAINED.**

| Type of Glassware. | Shape. | Size—ins. Max. Dia. | Depth. | Bottom Hole. | Type of Lamp. | Temperatures °F. Top. | Centre. | Bottom. |
|---|---|---|---|---|---|---|---|---|
| Clear ... ... | Pear ... ... | 10 | 8¼ | 1½ | 1,000 C.P. (Nominal) High Pressure. 10,000 B.Th.Us/hr. | 625 | 580 | 510 |
| Clear ... ... | Pear ... ... | 12⅜ | 11 | 1 | 10 mantle Super-heated Low Pressure. 12,500 B.Th.Us/hr. | 515 | 430 | 406 |
| Clear ... ... | Pear ... ... | 9 | 8½ | 13/16 | 5 mantle Super-heated Low Pressure. 6,250 B.Th.Us/hr. | 410 | 455 | 360 |
| Clear ... ... | Hemi-spherical ... | 6¾ | 4¾ | ¼ | 3 mantle Super-heated Low Pressure. 3,750 B.Th.Us/hr. | 380 | 406 | 318 |
| Clear ... ... | Pear ... ... | 8⅞ | 8¼ | 2⅛ | 5 mantle Low Pressure Safety Garage Lamp 3,750 B.Th.Us/hr. | 290 | 410 | 350 |
| Clear ... ... | Cylinder ... | 3 11/16 | 5 | — | Domestic Low Pressure Burner. 2,500 B.Th.Us/hr. | 335 | 268 | 94 |
| Opal-Heat-Resisting | Bell ... ... | 6½ | 5¼ | — | Ditto. | 350 | 275 | 130 |
| Opal ... ... | Bell ... ... | 6¼ | 6 | — | Ditto. | 335 | 248 | 135 |
| Flakestone ... ... | Bowl ... ... | 13¾ | 6½ | — | Ditto. | 125 | 145 | 165 |
| Supastone ... ... | Ornamental Bell | 6 | 4⅞ | — | Ditto. | 320 | 250 | 140 |
| Flakestone 2-ply ... | Ornamental Bell | 6⅝ | 6 | — | Ditto. | 320 | 245 | 140 |
| Opal and Clear 2-ply | Balloon ... ... | 5⅛ | 5⅛ | 1⅜ | Ditto. | 310 | 245 | 120 |
| Flakestone 2-ply ... | Ornamental Bell | 7¾ | 7¼ | — | Ditto. | 310 | 212 | 109 |
| Opal and Clear 2-ply | Mushroom ... | 9 | 6¼ | 5½ | Ditto. | 240 | 190 | 130 |




Well Glass for 400 w. Electric Discharge Lamps.




Opal Interior Lighting Fitting for 200 w. Lamp.

Fig. 6.

CHART SHOWING DIMENSIONS OF GLASSWARE FOR GAS AND ELECTRIC FITTINGS.

The graphs reproduced in Fig. 7 show heating-up and cooling-off curves for these globes.

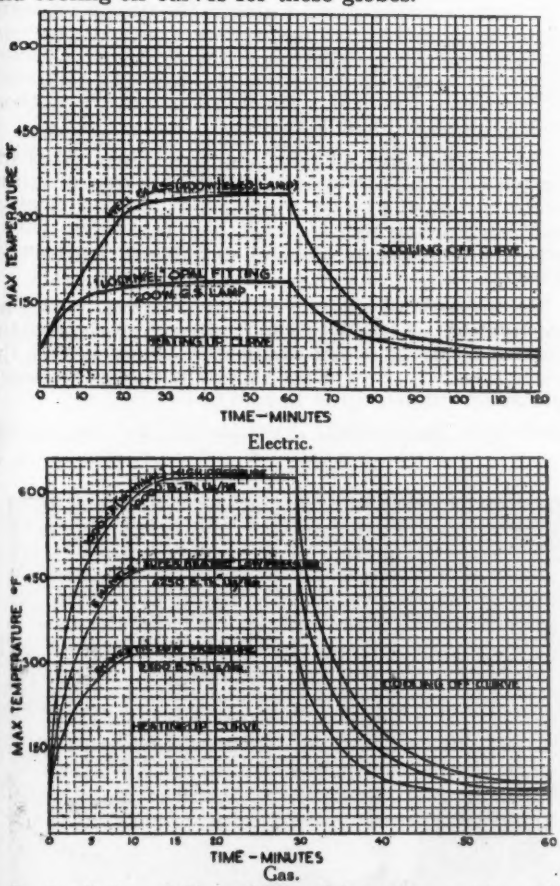



Fig. 7. Cooling off Curves showing Relation between Time and Temperature.

From the graphs it will be observed that the rates of normal heating-up and cooling-off vary with the type of globe under consideration, but that in every case the action is greatest during the initial stages. However, it must be remembered that during the thermal endurance test the globe is cooled off completely in five seconds, and it is thought that the table shown below is of some interest, since it indicates the relationship between normal cooling off, and that encountered during quenching.

**TABLE VI.—DATA ON RATE OF HEATING AND COOLING.**

| Type of Globe and Lamp. | Normal Rate of Heating Up °F/min. | Normal Rate of Cooling Off °F/min. | Rate of Cooling Off during Test °F/min. | Class of Test (See Next Table). |
|---|---|---|---|---|
| Globe for 1000 C.P. (Nominal) High Pressure Lamp ... | 145 | 112 | 6900 | A |
| Pear Shaped Globe for 5 mantle Superheated Low Pressure Lamp ... ... | 90 | 65 | 4008 | B |
| Bell Shape Globe for Domestic Low Pressure Burner ... | 44 | 40 | 1236 | C |

NOTE.—The rates of heating up and cooling off have been based on the temperature increase or decrease over the first two minutes, at the point on the globe where the highest temperature is reached.

Clearly, the test is a very stringent one, and should form a reliable guide, but that it is not too severe will be understood when it is realised that in practice in winter even more extreme conditions may be met.

By referring to the temperature diagrams (Fig. 8) it can be seen that on any glassware there are large temperature differences at various points and that generally the glassware is hottest at the point nearest or above the source of illumination.

At first sight it might appear reasonable to suggest that according to which part of the glassware (the hottest or the coldest) is first immersed, so the rejection or acceptance would be affected.

This has so far not affected the result in practice, presumably owing to the tendency of the glassware to rapidly equalise in temperature during the time lapse.

Another point of interest is to observe the effect of shape on the temperature distribution over the globe, as shown in Fig. 8.

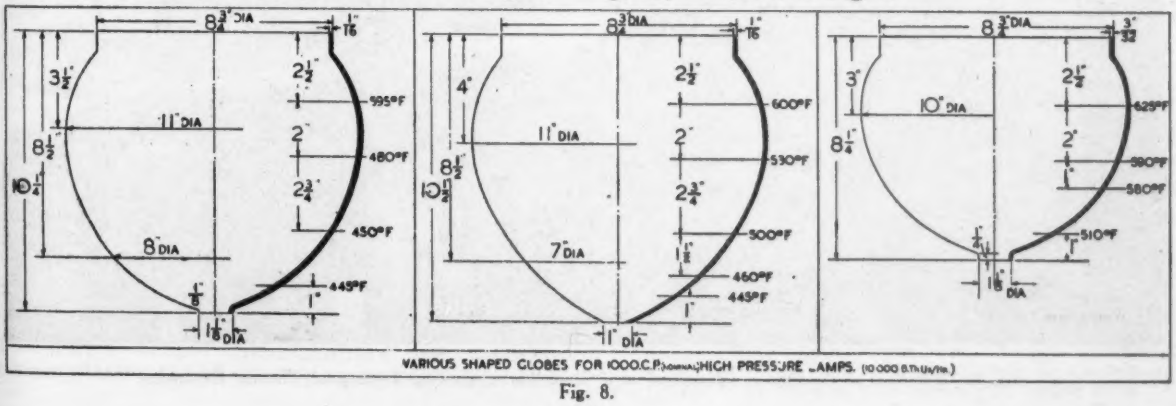



Fig. 8.

It appears that by varying the shape and size, the distribution of temperature can be controlled to some extent, and that by increasing the size, the temperatures tend to decrease. However, since all shapes of globes for any one type of lamp have the same neck diameter the maximum temperature does not vary greatly, and satisfactory temperature distribution is mainly a question of experiment as to which shape is best suited for any particular lamp.

**Extension of Tests.**

The importance of having standard tests to classify glassware in its relation to suitability for certain conditions of use has long been realised by lighting engineers. The gas and electrical industries in their dealings with the public encounter every condition of use, for example, ordinary dwelling houses, the generally more severe conditions of public halls, the still more severe conditions in factories and the certainly very extreme conditions experienced in street lighting and the outside illumination of buildings.

The National Test as it now exists, although developed to cover possibly the largest category of use, does not go far enough. From experience in the application of the test, it appears to be satisfactory only for heat-resisting glass suitable for use in domestic houses and public buildings, where no extreme conditions might be experienced, whereas in practice certain interior lighting fittings are very definitely subjected to conditions which are as severe as those met with on outdoor lamps.

In the year 1935, the Gas Light and Coke Company issued over a quarter of a million items of glassware for a very wide range of types and sizes of units, and conditions of use, which is possibly only a small proportion of the actual number sold on its area.

As a result of many years' experience in the investigation of failures, and after considering the results produced in the application of these tests, the author feels that an effort should be made to classify glassware under three headings:—

"A" Quality. — *For the most extreme conditions* i.e., for use on lamps of very high temperature,

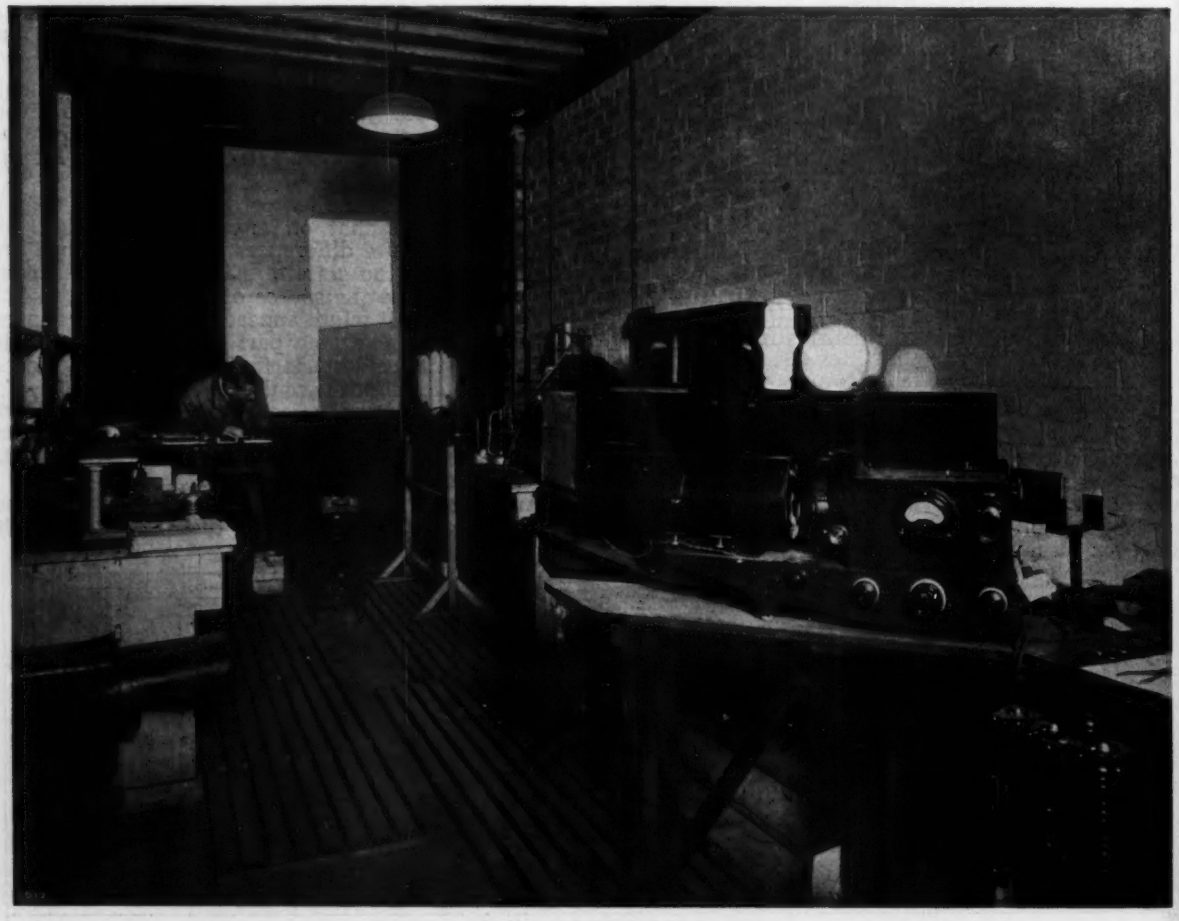


Fig. 9. A Portion of the Physics Laboratory at a Glass Works, showing Testing for Thermal Expansion.

such as high-pressure gas lamps, high wattage electric lamps, multiple super-heater low-pressure gas lamps.

"B" QUALITY.—*For the less severe or normal* conditions of use, such as indoor electric units, low-pressure gas lamps and burners, and burner units.

"C" QUALITY.—*For the purely decorative illumination glassware* of the variety that has a large sale, but does not really fall under the category of heat resisting, but which nevertheless, is satisfactory, providing care in use is exercised, and it is not exposed to sudden and severe draughts.

If this were agreed to, it is suggested that the three tests shown in Table VII. would be suitable, and indeed are being found suitable, to distinguish between these three classes.

**TABLE VII.—ALTERNATIVE CONDITIONS OF TEST.**

| Quality. | Period of operation. | Lapse of time between extinction and immersion. | Temperature of water. |
|---|---|---|---|
| A | 1 hour | 30 sec. | 10°C. (50°F.) |
| B | 1 hour | 45 sec. | 55°C. (131°F.) |
| C | 1 hour | 90 sec. | 100°C. (212°F). |

TEST A.—This is the original B.S.I. test, and Manufacturers need have no misgivings as to the severity of the test, since the high quality of modern heat-resisting glass for this class of work gives them a large margin of safety, and puts the glassware in a distinct class.

TEST B.—This is the present B.S.I. test, and from practical use of the test it has been found to give the manufacturer and user a line of demarcation between glassware that will be definitely satisfactory in use under *all* conditions normally encountered with this grade of glass and that which is less satisfactory.

TEST C.—This was developed at the research laboratories of the Gas Light and Coke Co., at Watson House, to deal with the several types of glassware often of intricate shape and of special manufacture, used for household lighting. This cannot in the true sense be regarded as in the heat-resisting class. The public are naturally attracted by the decorative appearance of this type of glassware, and generally realise from experience that some care must be exercised in the use of it. It was found that some test was necessary to ensure that a reasonable life could be expected. Glassware of this class is invariably used for both gas and electric units, and although the test is very mild it gives a measure of security to manufacturer and user, particularly in the case of use with gas units where higher temperatures are encountered.

It is felt that the adoption of these three tests would immediately enable manufacturers and users to classify glassware and lighting units, and relate them to temperature and conditions of use, and therefore prevent difficult disputes as to failures of glass in use.

The author wishes to express his appreciation of the privilege to present this information, and especially to acknowledge his indebtedness to the directors of the Gas light and Coke Co. for the facilities granted, and their permission to prepare and publish it.

The author's thanks are specially due to Mr. P. H. Burke, Mr. J. C. Stockwell, and other colleagues for the help received in the collection and preparation of these notes, and to Mr. C. R. Austen for the preparation of the film describing the methods of test. Thanks are also due to Messrs. Chance Bros., Ltd., James A. Jobling and Co., Ltd., and Hailwood and Ackroyd, Ltd., for the provision of photographs and information.

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Fig. 10. Removing a globe from a mould. This picture illustrates the high degree of skill required to ensure a sufficient and uniform degree of thickness of large glassware for lighting units.

# THERMAL TESTS FOR ILLUMINATING GLASSWARE

## DISCUSSION

Dr. J. W. T. WALSH said that all three papers were outstanding examples of the manner in which illuminating engineers were trying to get over their difficulties. The paper by Mr. Buckley and that by Mr. Dunkley and Mr. Stevens were the outcome of difficulties in which one of the British Standards Institution Committees found itself, i.e., the Lighting Fittings Committee, and he well remembered hearing the pessimistic remarks which were made round the table of that committee as to the possibilities of devising a satisfactory thermal endurance test and the equally pessimistic remarks as to getting a concise way of describing the light distribution from fittings. Therefore the authors deserved a word of hearty congratulation for having come to the rescue of the committee and helped it out of its difficulties. At the same time the committee would heartily endorse what the authors had said, viz., that the solution presented in these papers did not represent the last word and that there was a good deal more experience yet to be gained. Nevertheless, it was to be hoped that as the result of experience and the application of the various tests which had been described it would be possible to dot the i's and cross the t's of the tests which had taken us such a very long way towards a solution of the troubles.

Dr. W. M. HAMPTON said that Mr. Dunkley would doubtless be the first to disclaim any specialised knowledge of glass manufacture, but as he has had the courage, or the temerity, to venture to discuss this complex subject, it was to be assumed that he expected some criticism.

Under the heading of thermal endurance, he gave a formula which was first put forward by Winkelmann and Schott to cover their experimental results, using small cubes of glass. This formula, in addition, made the assumption that the rate of change of surface temperature was infinite. It was obvious that neither of the assumed conditions applied to hollow globes. Stott, and, later, the present speaker, with one of his colleagues, put forward a modified expression which in the latter case was based on the assumption that the article was an infinite, flat plate. This assumption was not as far-fetched as it seemed so long as no edge was allowed to come in contact with the cooling liquid. Further, the rate of change of surface temperature was assumed to be finite. These assumptions led to the modified expression: $\frac{P\ (1-\sigma)}{EA}$ (using the nomenclature in the paper), which had the two advantages of containing only four constants instead of six, and that it had been confirmed that the experimental values given by the standard test were in agreement with the figures calculated from the formula. For these reasons he suggested that the form of expression given by Mr. Dunkley should be dropped and the modified expression substituted.

Mr. Dunkley further said that a difficulty with the use of heat-resisting globes was the development of a reddish stain during use. It was possible that some misunderstanding may occur with regard to this. Experiments which he had carried out had shown that this was not the ordinary change of colour found in certain types of globe on exposure to sunlight; such change was usually due to the presence of manganese and heat-resisting glasses did not contain it. Analysis shows that the colour was due to copper. This copper had undoubtedly come from the fitting in which the globe was installed and was due primarily to the very high temperatures reached by high-pressure gas units. The difficulty was, therefore, one of design and not one which concerned the glass maker.

In the second paper by Mr. Dunkley and Mr. Stevens an expression was used which seemed likely to be misunderstood. The authors said that the figures in Table 2 showed the spread which "represents unavoidable variation in manufacture": while not denying that variation in manufacture must occur, he (Dr. Hampton) did state emphatically that the sort of spread indicated was inevitable in such tests and had nothing to do with manufacture. He had elaborated this thesis on a previous occasion and merely wanted to draw attention to it now.

A little later on in the paper the authors said that the "spread of 130° C. to 160° C. represented the best accuracy of observation," but this was denied by the authors themselves, for a little higher they said that the quenching temperature was raised in 5° C. increments and, therefore, the accuracy of observation was about 2½° C. The spread, therefore, was due to the inherent nature of the material and was not due to the accuracy of observation.

*Communicated.*—On reading over the paper again it occurs to me that what the authors are really endeavouring to do is to decide whether or not units are satisfactory for the purpose for which they are designed.

I suggest it is hopeless to expect users in general to break a number of expensive units, and it is clear from what the authors have said and from what is known of the variation in the thermal test results that a number must be broken before any conclusion whatever can be drawn. I suggest that the cheapest and most satisfactory way of tackling this problem is to endeavour to correlate the thermal endurance of the glass *qua* glass with its performance in the form of fittings. This implies that with a new design an investigation must be undertaken by the designer to decide what thermal endurance, as measured by a

specific thermal endurance test, is needed in order that the unit should be satisfactory. Subsequently, all that is necessary is that a specification shall be drawn up saying that the glass used for this particular unit shall have a thermal endurance figure of not less than "x." The test to be employed for this could be any standard test, and that put forward by the Society of Glass Technology has been shown to be satisfactory in practice.

This method of working would not only be much less expensive, but would also be in accordance with the procedure in other industries. An engineer does not, in general, say that a number of bridges shall be tested to destruction in order to prove that they are satisfactory for the job, but he calculates the stresses (or determines them from small models) which are likely to be met in practice, and then specifies the tensile strength, elastic limit, and so on of the material from which the bridge is to be built.

Work such as that carried out by the authors is valuable, but would be tremendously more so if it were correlated with the result of thermal endurance tests. As a result of such an investigation it could be shown that a glass of one thermal endurance failed in, say, 90 per cent. of the cases in this particular unit, but a glass of, say, a higher thermal endurance was successful in 90 per cent. of the cases, and therefore, making some assumption as to the percentage breakage which could be expected in practice, it would be simple to lay down a minimum thermal endurance, as determined by the standard test, which would be satisfactory. This would be a figure to which the glass manufacturer could be held, and it would divide the responsibility for breakage fairly between the maker and the designer of the unit.

Mr. F. C. SMITH remarked that although he knew nothing of the technique of glass manufacture, he had been surprised to hear Dr. Hampton say that the pink discoloration sometimes found on heat-resisting glassware used on high-pressure lamps was due to copper. It seemed improbable that the temperature was high enough to cause the metals to be volatilised, and he believed it would be very difficult to prove that the defect in question was traceable to the copper of the fitting.

Dr. HAMPTON said he could not, of course, say what was the cause of the defects in the case Mr. Dunkley had referred to, but he certainly had seen cases where the colour was due to the copper in the fitting since the glass in the remainder of the globe did not contain copper.

Mr. SMITH replied that he was familiar with this pink stain, and knew cases in which it definitely had occurred under conditions in which Dr. Hampton's suggestion could not account for the trouble, although he would not say that it could never occur under such conditions. At the same time, if too much stress was placed upon the small defects which occurred in present-day heat-resisting glassware, there would be a tendency to underrate the remarkable improvements which had taken place in recent years. For instance, in the case of high-pressure gas street lighting breakage of globes some fifteen to twenty years ago was very high, but to-day it was negligible.

The gas industry was greatly indebted to the glass manufacturer, and in particular the English glass manufacturer, who had done so much to improve the quality of heat-resisting glassware. In consequence he, personally, was not disposed to say a great deal about these minor defects.

Referring to the test which Messrs. Dunkley and Stevens had described, he confirmed that these tests had been very useful in differentiating between qualities of glassware when purchasing for street lighting purposes.

In tests of this kind the important criterion was whether the results obtained at the testing station enabled one to anticipate the performance of the articles examined under practical conditions. Justification for the particular test that the authors had described was that there was close correlation between the results obtained in the laboratory and the practical results as indicated by the percentage of breakages which occurred in practice.

*Communicated.*—Since the discussion I have examined some of the pink stains referred to, and in these particular cases I confirm the statement made by Dr. Hampton that copper was found.

Dr. S. ENGLISH said that it was 20 years ago that he first began work on the thermal endurance of glass, and since then he had been closely in touch with most of the work done on this subject, consequently he would look at Mr. Dunkley's paper from a rather different angle than most people, and his views might not coincide with the general opinion regarding the paper.

At the end of the paper, Mr. Dunkley had given references to several sources of information, and presumably these were sources which had been used in the compilation of the paper or, at any rate, some portions of it. With respect, however—and certainly no disrespect whatever, Dr. English suggested that the publications mentioned were of the popular variety and were not serious technical publications; Mr. Dunkley would have been better advised to have looked at some of the modern and more precise technical publications on the subject. If he had done so, he would not have made such categorical and definite statements with regard to the behaviour of glass. Years ago, said Dr. English, he had been definite himself, but he had learned much since then and was now indefinite. Therefore, he could not substantiate some of the statements in Mr. Dunkley's paper. For instance, it was suggested that strain was the cause of the breakage of glass in use and that this was a cause of poor thermal endurance. To a certain limited extent that might be so, but, on the other hand, in certain circumstances, he said it was not so. He gave two examples. (i) Jam jars were filled with hot jam and had to withstand a severe thermal shock. Many jam jar manufacturers deliberately strained their jars to enable them to withstand that shock. (ii) Armour-

plate glass or toughened glass was particularly good from the thermal endurance point of view. It derived its thermal endurance properties simply by reason of the fact that it was very badly strained, but it was strained symmetrically and carefully.

In view of such examples Dr. English therefore remarked that the suggestion that cropped up in connection with the first issue of B.S.S. 324, and had been repeated now, that bad annealing caused bad thermal endurance, was only true to a limited extent.

With regard to the Winkelmann and Schott formula, which included quite a number of the physical properties of glass, he did not think it included the most important, viz, heat absorption, yet from the illuminating engineer's point of view this was the thing that really mattered. If glass allowed the heat to go through entirely unabsorbed its temperature would not rise and there would be no risk of fracture. The importance of heat absorption in this connection was illustrated in the case of floodlight colour screens: blue glasses which absorb heat freely break very much more frequently than red glasses, which allow the heat to pass through unabsorbed to a much greater extent.

Turning to the paper by Messrs. Dunkley and Stevens and the rod tests, Dr. English said he could amplify what was said in the paper on this point. These tests were made in about half a dozen different laboratories, and quite a fair share of the variation in breaking temperature from 150° to 180° which had been mentioned may not have been the fault of the glass but of the calibration of the thermometers used in the tests. As to the testing of globes, Dr. English asked whether the authors had had any experience of a tendency to crack from the neck near the positions of the three screws. He had heard it suggested that cracking took place preferentially from the positions of the screws and some confirmation, or otherwise, of that would be interesting. Personally, he had no evidence to support such a suggestion.

Mr. A. CUNNINGTON remarked that as a user he had been wondering what conditions in actual practice these tests were endeavouring to reproduce. Globes broke from all sorts of reasons. The raindrop test was a practical one and reproduced conditions which could be understood, but it used to be considered that an important cause of breakage in ordinary gas fittings was the impinging of sudden heat upon one particular spot in the globe when a mantle broke. Perhaps, however, the improvement in glass rendered that possibility more remote than formerly, and such conditions nowadays might be taken care of by the tests described.

Mr. C. A. MORTON remarked that the presence of a hole in the bottom of the bowl must make a considerable difference to the results obtained. The existence of the hole must reduce the water pressure to be resisted, and will tend to shorten the time of immersion. The difference in temperature between the two sides of the bowl is thus likely to be different from that resulting from a similar bowl without a hole. From that point of view the value of the test was limited to bowls of a given type.

Mr. S. F. DUNKLEY, replying, said that he appreciated very much the very interesting discussion which had followed, despite the small amount of time available.

As regards the remarks of Dr. Hampton and Dr. English, he quite appreciated their points of view, but at the same time, knowing them for so many years, could not take their remarks too seriously. His reply to Dr. Hampton, who unfortunately had to leave to catch a train, was made very clear in the introduction to the paper, in which he pointed out that his object was to create a wider interest and a greater degree of co-operation amongst the interested parties, in especial the users and merchants who were probably not so familiar with the technique of glass manufacture as the actual manufacturers.

In reply to the remarks made by Dr. English concerning the effect of fixing screws on cracking, he stated that the general tendency of a globe on test was to crack from or around the neck, and in his experience the screws had very little effect on the result, in fact, since the highest temperatures were almost always attained in the vicinity of the neck, one would naturally expect cracking to occur here if anywhere.

Replying to Mr. Cunnington, Mr. Dunkley stated that the object of these tests was to simulate the most severe conditions met with in use, with possibly some margin of safety, and by means of these tests to reduce maintenance costs by differentiating between good, bad, and indifferent glassware. As regards the effect of broken mantles, he believed that with a good quality heat-resisting globe, the effect of an impinging flame would not cause fracture, in fact, such a test was actually carried out on a high-pressure gas lamp, the unit burning for several hundred hours with a broken mantle, and the glass at one point reaching 1,000°F. without cracking.

In replying to Mr. Morton, he agreed that the question of the method of immersion was a point worthy of further consideration.

In conclusion, he pointed out that he himself was responsible for quarter of a million pieces of glassware of all classes used per annum, and he considered some form of control vitally necessary in the interests of not only his company, in order to ensure that they received value for money, but even more so in the interest of the consumers, in order to ensure that they received value for money, satisfactory service, and safety in use.

This being the case, some tests were clearly necessary, if only, as a previous speaker had pointed out, to separate the chaff from the wheat. He therefore felt it absolutely necessary that the makers not only of lighting fittings, but also of glassware, should co-operate together with a view to classifying glassware in categories suitable for the particular design of fitting.

Mr. W. R. STEVENS, replying, said that the doubtful wording to which Dr. Hampton had referred would be modified; there was, of course, no suggestion of faulty or uncontrolled manufacture intended. So far as the spread was concerned this could only be indicated by statistical representation, and an attempt had been made to do this. (In his communicated remarks Dr. Hampton suggests that " it is hopeless to expect users to break a number of expensive units," and that the " most satisfactory way of tackling this problem is to endeavour to correlate the thermal endurance of the glass *qua* glass with its performance in the form of fittings." Dr. Hampton seems rather to have deviated from the original intention of these tests. One imagines that most fittings manufacturers of repute do already consider the quality of glassware in conjunction with the fitting. But the present tests were intended for the consumer, so that he could check the designer's work in a reasonably accurate and impartial manner, just as, for example, independent tests to destruction can be performed on electric lamps without checking separately the filament, the degree of vacuum, and so on.)

The point made by Mr. Smith regarding the relation between laboratory tests and practical results, is probably the crux of the whole matter. That was why the authors had been so anxious to have this discussion in order that anybody with useful data might bring them forward.

Replying to Dr. English, Mr. Stevens said that preferential cracking at the screw positions had not been noticed.

Mr. Morton's remark concerning the effect of a hole in the bottom of the globe when the bathing test was applied was probably correct, and for that reason a bowl under test was swung over so that the water ran in quickly through the neck. At the same time there was a lack of data as to the best method of bathing the bowl for this test. If the bowl were immersed neck first, would the result be wildly different from immersing it base first? It had been found that by immersing the bowl base first, it was possible to exert sufficient pressure to break it by brute force.

In reply to Mr. Cunnington, the bathing test was not intended to simulate practical conditions, but to be a severe overload test, which, it was endeavoured to show, could be correlated with practical results.

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